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TNT EQUIVALENCE OF TWO PLASTIC-BONDED EXPLOSIVES FOR INTERNAL BLAST AND GAS PRESSURES

Wilfred E. Baker
Wilfred Baker Engineering
Donna W. O'Kelley
Southwest Research Institute

ABSTRACT

Past internal blast testing within an eight-scale loads model of a multi-bay containment structure has provided a data base for both reflected internal blast loads and long-term gas phase pressures within a strong containment structure. These data are analyzed to determine TNT equivalence for internal blast loading, and separate values for TNT equivalence for gas phase pressures, for two plastic-bonded explosives, PBX-9404 and PBX-9502. Different values are obtained for the two phases of the internal blast loading, and both differ from values which would be estimated on the basis of heats of explosion relative to TNT.

I. INTRODUCTION

It is common practice in estimating hazards or blast loads from detonating high explosives to express the masses or energies of the explosives as equivalent masses or energies of TNT. One reason for this conversion is that many of the "standard" curves or equations for air blast wave properties for high explosives (Refs. 1-3) are based on data fits to tests with TNT. Another reason is that some methods for predicting transient loads on blast-resistant structures are applicable only for blast loading from TNT explosive (Ref. 3).

The two most prevalent methods for estimating TNT equivalence are comparisons based on free-field blast testing, and comparisons based on relative heats of explosion.

Generally, the comparisons based on free-field blast measurements show somewhat different equivalence values for peak overpressure as opposed to specific impulse (Ref. 4), and/or variation of equivalence with scaled distance (Ref. 5). One of the latest set of comparisons of this nature appears in Ref. 6.

The use of relative heats of explosion has the virtue of ease of measurement (via bomb calorimetry), and simplicity. A single conversion number results, rather than one which differs for different blast parameters or varies with distance.

In internal blast loading of structures from high explosive detonations, the loading on various interior surfaces consists of an initial reflected

shock wave, followed by several later waves arriving after reflection from other surfaces, superimposed on a much longer duration gas pressure which has a relatively slow rise time. Fig. 1. shows a record of this loading in a model containment structure with no venting. Usually, the shock loading and gas pressure phases are considered separately in estimating their properties (see Ref. 7), and then recombined in some simplified form to estimate combined internal blast loading for structural response calculations (again, see Ref. 7).

One phase of an extensive internal blast test program conducted by SwRI for Pantex Plant was directed toward establishing internal explosion TNT equivalence values for several explosives. All tests were run in an eighth-scale loads model of the Damaged Weapons Facility, which was repeatedly subjected to a number of internal detonations with no damage to the model. Ref. 8 contains a description of the tests in this phase, as well as tables of all reduced data from the many transducers flush-mounted in the model. Figs. 2 and 3 are sections through the model, showing some of the transducer locations.

In tests within this unvented model, the internal configuration was varied in two ways. The equipment and personnel locks were left open for some tests, or closed for some tests by bolted and sealed covers shown in Fig. 3. For this phase, we also installed a cover inside the entrance to the high bay for some tests. By varying the type of explosive, charge weight and effective internal volume, we could obtain extensive internal blast and gas pressure data over a range of "loading densities" W/V. A series of TNT charges of a single weight were detonated for comparison.

This paper presents TNT equivalents for the plastic-bonded explosives PBX-9404 and PBX-9502 for internal explosions, based on the test data from Ref. 8.

II. DESCRIPTION OF TESTS

A total of 37 tests were conducted during the Phase II series. All explosive charges were detonated within the high bay section of the model, and all but a few were in the same location (location A in Ref. 8). Most of the charges were bare explosive spheres, centrally initiated.

Three 1.280 lb TNT spheres were detonated to give base data for comparing internal blast loads from other explosives. The most extensive data obtained for other explosives were for PBX-9404 and PBX-9502 plastic-bonded explosives. Charge shapes for these explosives were also spherical, and weights ranged from 0.495lb to 0.993lb for PBX-9404, and 0.639lb to 1.285lb for PBX-9502. Table 1 gives the composition by weight of these two explosive mixtures. For complete test details, see Ref. 8.

The primary test data were the pressure-time traces recorded at various locations on the interior surfaces of the model. Data were reduced to separate shock loads (initial and later reflected) from quasi-static or gas pressure loads. Following sections cover methods for estimating TNT

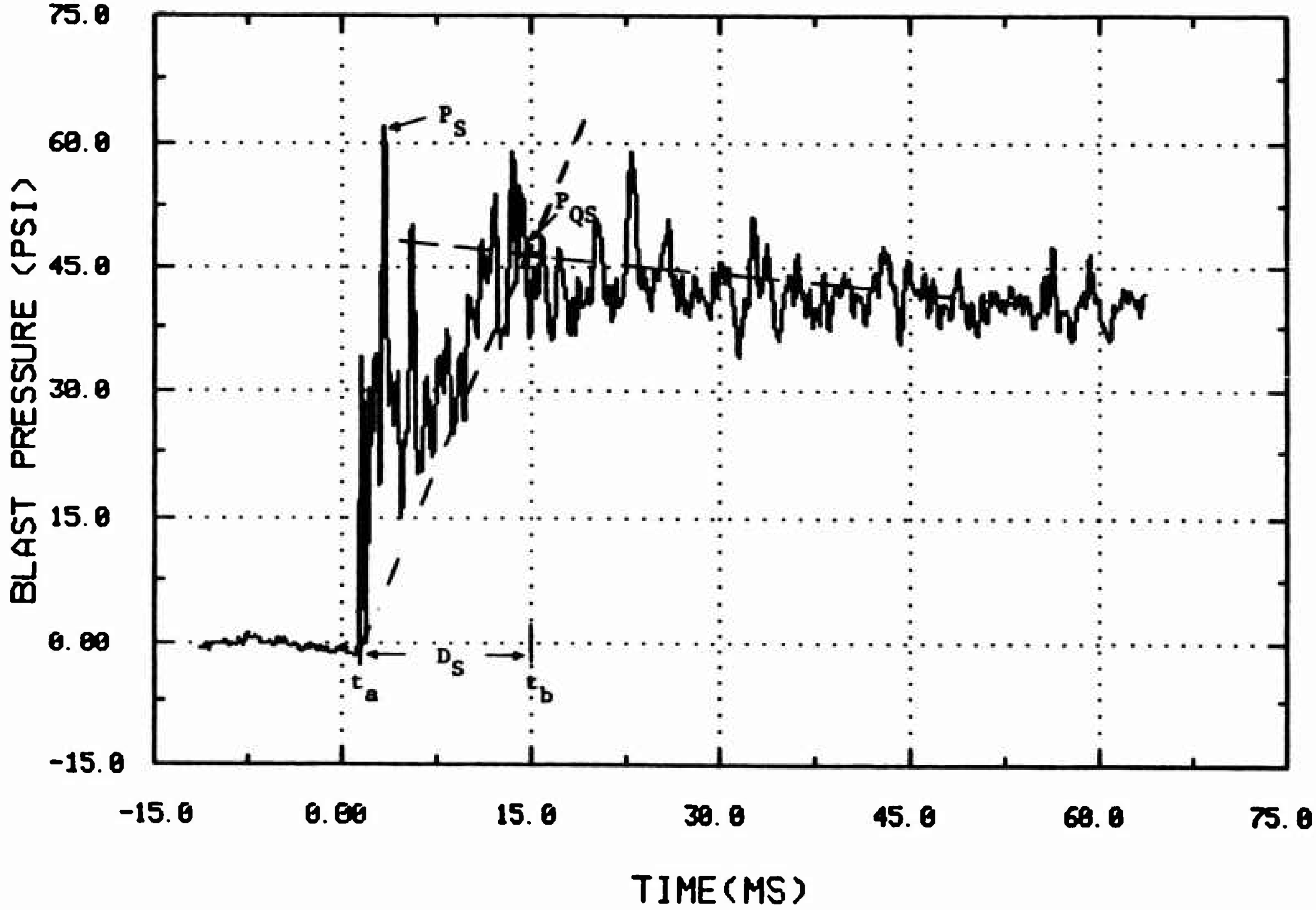

Figure 1

Typical Internal Blast and Gas Pressure Trace
for a Blast Containment Structure

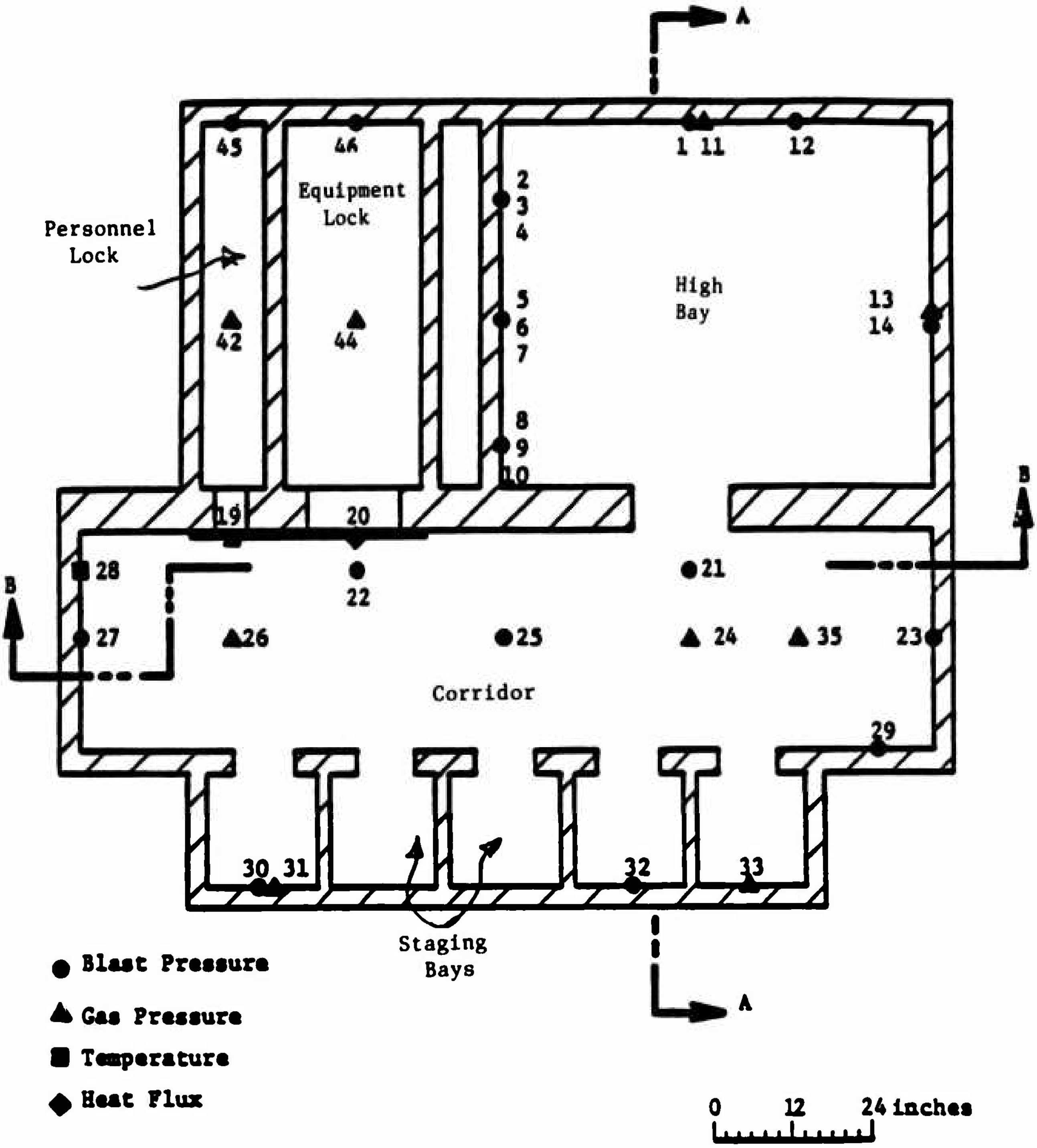

Figure 2

Horizontal Section through DWF Model

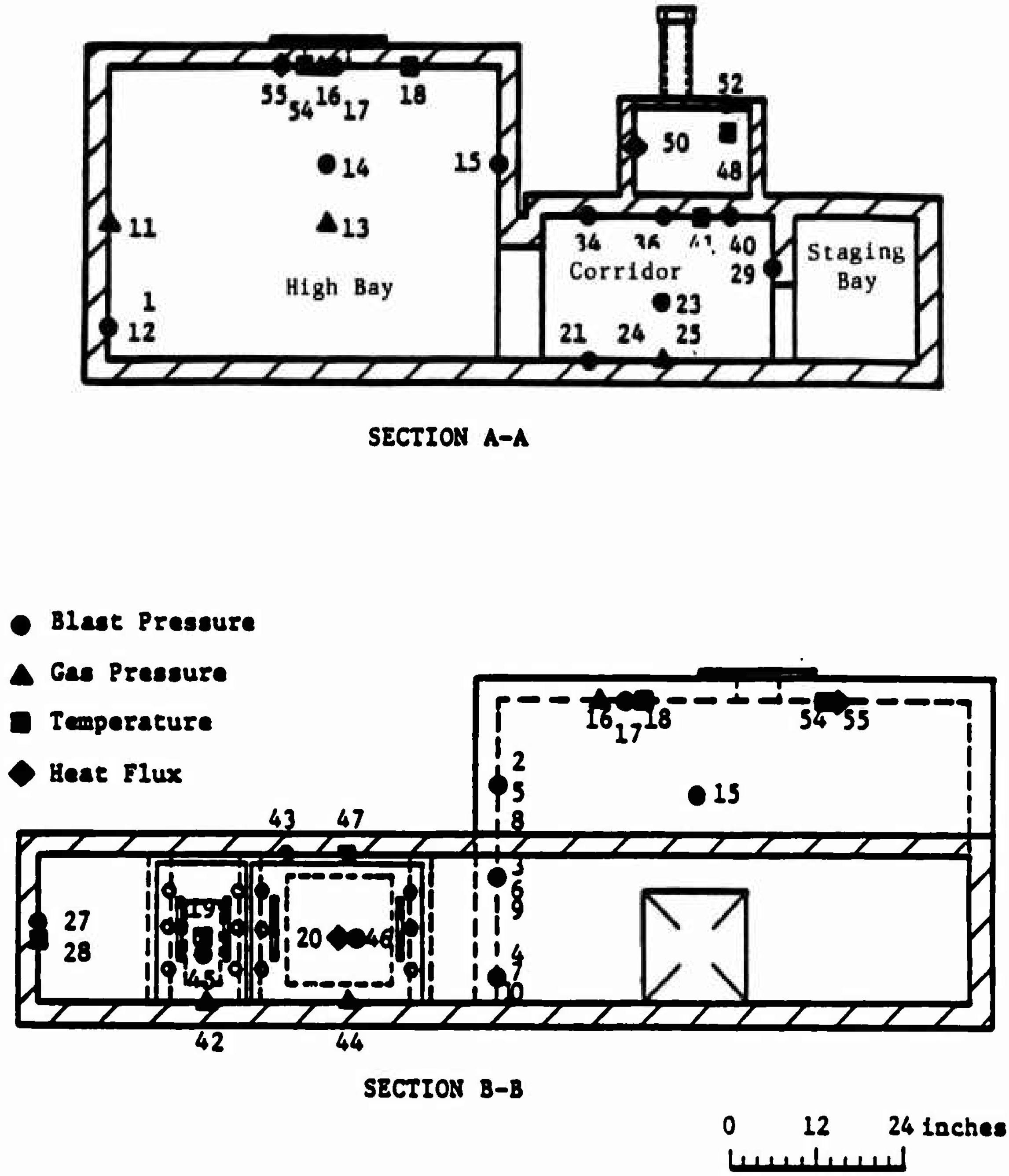

Figure 3

Vertical Sections through DWF Model

equivalence from the pressure records, for the two phases of internal blast loading.

TABLE 1

Composition of Two Plastic-Bonded Explosives

Explosive	Composition	% by Weight
PBX-9404	HMX	94
	NC (12.0% N)	3
	CEF*	3
PBX-9502	TATB	95
	Kel-F 800**	5

* CEF is Tris-β-chloroethyl-phosphate
** Kel-F 800 is Chlorotrifluorethylene/vinylidine flouride copolymer, 3:1.

III. TNT EQUIVALENCE FOR INTERNAL BLAST LOADING

A. Method of Analysis

The method of analysis is based on direct, gage-by-gage comparisons of reduced internal blast data. We restrict the comparisons to those tests with the same charge locations and the same model configuration (open interior doors). In this manner, we eliminate all variations in data except charge weight and type.

There were fourteen blast gage locations in the high bay used during these tests, three TNT tests of the same weight, nine PBX-9404 tests divided among four charge weights, and eight PBX-9502 tests divided among four charge weights. These data are given in Tables 5-9 and 12-15 in Ref. 8, but are too voluminous to repeat here.

The procedure for estimating TNT equivalence for blast from these data is as follows:

1) For each gage location, make a least-squares fit to a linear relation between peak overpressure values and charge weight of PBX-9404 or PBX-9502.

2) Determine a value for PBX charge weight from the fit which gives the same overpressure as the average of the three TNT tests for the same gage location.

3) Divide PBX charge weight by weight of TNT charge, i.e., 1.280 lb. This value is one number for TNT equivalence, based on peak overpressure.

4) Repeat steps 1) through 3) for each gage location.

5) Average TNT equivalents to get overall TNT equivalence based on overpressures. Calculate a standard deviation, as well as the average.

6) Repeat steps 1) through 5) for impulse data, and obtain TNT equivalence based on impulse.

B. Results

Table 2 gives the results of this procedure, for PBX-9404 explosive, by gage location and means and standard deviations. Blanks in the table indicate no reasonable intercept of our straight-line data fit. Table 3 gives results for PBX-9502 explosive. For these data, we were always able to get intercepts for the data fit.

Table 2. Internal Blast TNT Equivalents for PBX-9404 Explosive

Gage Loc.	Overpressure TNT Equivalent	Impulse TNT Equivalent
1	0.898	0.757
2	0.620	0.527
3	1.095	0.836
4	0.915	0.877
5	0.811	0.773
6	0.920	0.680
7	0.755	0.846
8	0.579	--
9	0.827	0.987
10	0.759	0.803
12	0.687	0.577
14	0.488	0.573
15	0.738	--
17	1.073	0.838
Average	0.798	0.756
Std. Dev.	± 0.175	± 0.140

TABLE 3. Internal Blast TNT Equivalence for PBX-9502 Explosive

Gage Loc.	Overpressure TNT Equivalent	Impulse TNT Equivalent
1	1.33	0.968
2	1.196	0.869
3	1.347	1.038
4	1.196	1.034
5	0.844	1.062
6	1.786	1.057
7	1.215	1.157
8	0.928	0.848
9	0.932	1.10
10	1.152	1.165
12	1.568	0.972
14	0.717	0.756
15	1.056	1.403
17	1.1996	0.957
Average	1.176	1.028
Std. Dev.	$\pm$ 0.283	0.159

IV. TNT EQUIVALENCE FOR INTERNAL GAS PRESSURES.

A. Method of Analysis

The method of analysis for TNT equivalence for peak internal gas pressure P_{Qs} is much simpler than analysis for TNT equivalence for internal blast loading, because peak gas pressures were found to be independent of gage location for any model configuration. So, it was possible to average all of these values for all gas gages for a given test, and compare to averages for the TNT series as well as past data for TNT. This was done and reported in Ref. 8.

The method is best described by referring to Fig. 4, which shows peak quasi-static pressures from these tests plotted as a function of the "loading density", W/V. Also plotted is a portion of the curve for TNT, fitted to earlier TNT data (see Ref. 7). Then, each data point was adjusted to lie on the curve by choosing the value of W/V which corresponded to the measured pressure. TNT equivalence for that point was then taken as the ratio of equivalent W/V to actual W/V. For a given explosive, the equivalence values were then averaged, and a standard deviation was calculated.

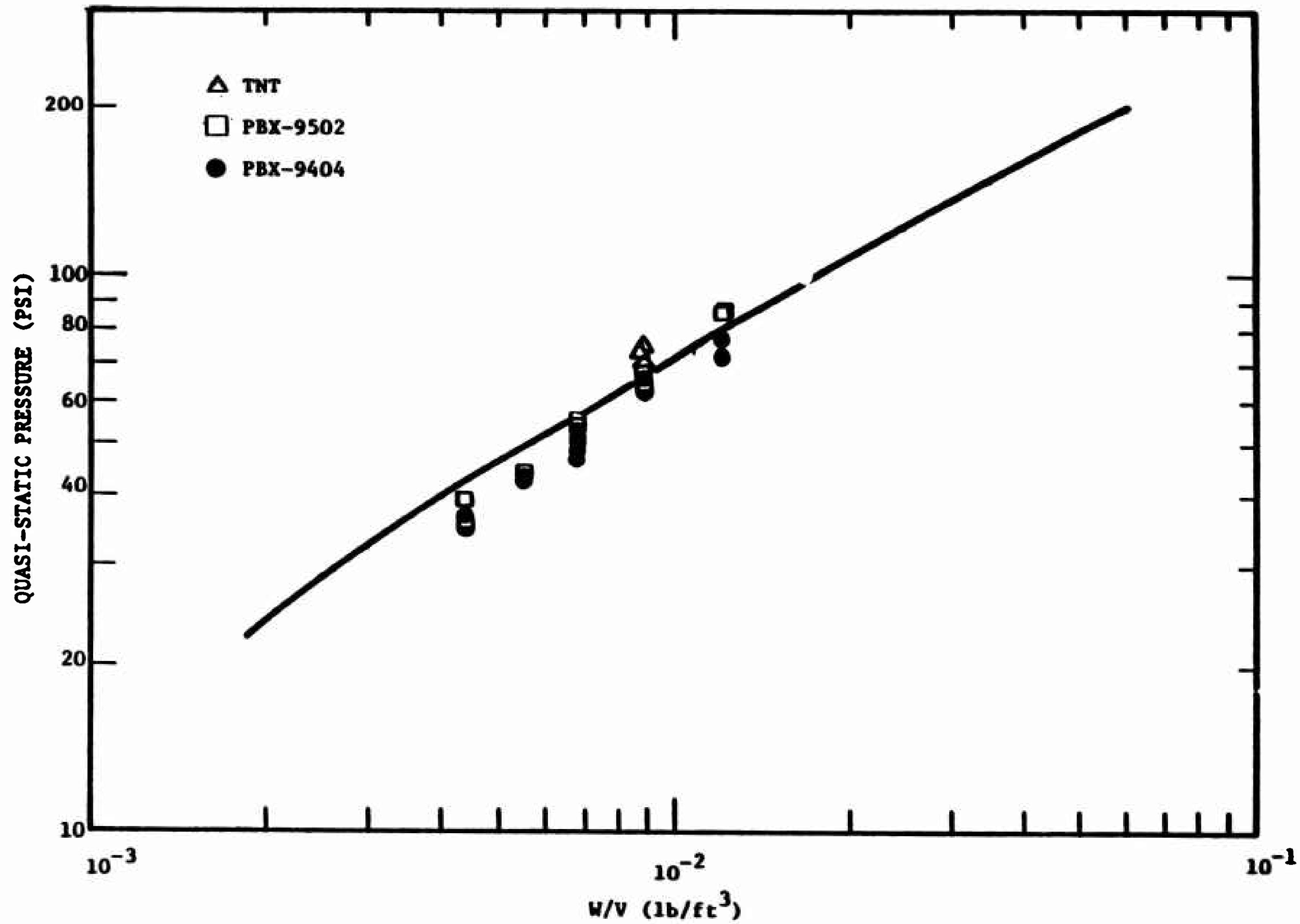

Figure 4

Summary of Quasi-Static Pressure Data

B. Results

Table 4 gives the results of estimating TNT equivalence for quasi-static pressure for PBX-9404 and PBX-9502 explosives. Not that both show values less than one, when compared to the "standard" P_{Qs} curve in Ref. 7. Also note that the average quasi-static pressure for the three TNT charges fired in this program was somewhat greater than the standard curve value. We retained the conversions to the standard curve for the other explosives, however, because it is in fairly wide use.

V. DISCUSSION

We can summarize the TNT equivalencies estimated in this paper, and those predicted relative to TNT, and have done this in Table 5. The numbers in parenthesis under equivalence based on quasi-static pressure are normalized to the measured values for TNT during these tests, rather than to a "standard" curve based on previous tests. We suspect that the earlier values are lower than the current ones because all earlier tests were conducted in vented structures, while these test were conducted in a pressure-tight, nonvented structure. The values for P_{Qs} in our test were easily read from the records because they did not decay, while values from vented tests were always estimates requiring extrapolation of the early parts of the gas pressure records.

Table 5. Comparison of TNT Equivalences on Various Bases

Explosive	Bases	TNT Equivalence
PBX-9404	Internal blast overpressure	0.798
	Internal blast impulse	0.756
	Quasi-static pressure	0.813 (0.680)
	Relative heats of explosion**	1.11
	Relative heats of combustion*	0.630
PBX-9502	Internal blast overpressure	1.176
	Internal blast impulse	1.028
	Quasi-static pressure	0.920 (0.770)
	Relative heats of explosion**	0.815
	Relative heats of combustion*	0.746

* Measured in Ref. 7
** Based on calculated values.

Review of Table 5 indicates the following:

- o Values for TNT equivalence for internal blast based on overpressures and impulses are close enough for a given explosive to average these values and use a single conversion number.

Table 4. TNT Equivalence of Two Plastic-Bonded Explosives for Quasi-Static Pressure

TEST NOS.	EXPLOSIVE	P_{QS} (PSI)	(W/V)(LB/FT^3) EQUIVALENT	(W/V)(LB/FT^3) ACTUAL	TNT EQUIV., ε_g
42,43	PBX-9404	75.7	1.05×10^{-2}	1.23×10^{-2}	0.854
18,19	PBX-9404	62.3	7.60×10^{-3}	8.86×10^{-3}	0.857
27,28,29	PBX-9404	51.5	5.6×10^{-3}	6.82×10^{-3}	0.821
13,24,25	PBX-9404	49.5	5.4×10^{-3}	6.82×10^{-3}	0.792
14	PBX-9404	48.6	5.2×10^{-3}	6.80×10^{-3}	0.765
20,21	PBX-9404	43.1	4.4×10^{-3}	5.54×10^{-3}	0.815
22,23	PBX-9404	36.1	3.5×10^{-3}	4.43×10^{-3}	0.790
					$\boxed{0.813 \pm 0.034}$
15,16,17	TNT	75.3	1.05×10^{-2}	8.79×10^{-3}	1.195
40,41	PBX-9502	87.6	1.35×10^{-2}	1.22×10^{-2}	1.107
32,33	PBX-9502	65.2	7.8×10^{-3}	8.85×10^{-3}	0.881
38,39	PBX-9502	54.3	6.4×10^{-3}	6.80×10^{-3}	0.941
34,35	PBX-9502	44.2	4.6×10^{-3}	5.56×10^{-3}	0.827
36,37	PBX-9502	37.8	3.7×10^{-3}	4.39×10^{-3}	0.843
					$\boxed{0.920 \pm 0.113}$

- o The TNT equivalence values for internal blast do not correlate with either relative heats of explosion, or relative heats of combustion, for either PBX-9404 or PBX-9502 explosives.

- o TNT equivalence for quasi-static pressure correlate reasonably well, when based on these test results rather than compared to standard curves, to relative heats of combustion for both test explosives compared to TNT.

These comparisons point out again that the concept of TNT equivalence is inexact, and that simple conversions based on relative heats of explosion (as in Ref. 7) can lead to either overprediction or underprediction of blast loads. Similarly, TNT equivalencies for quasi-static pressure differ from equivalencies for internal blast loads. But, for the specific range of loading densities employed for these tests, a simple conversion based on relative heats of combustion is reasonably accurate.

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